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Water Quality Assessment of River Bonsa in Tarkwa, a Mining-impacted Area of Ghana

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Authors' contributions

This work was carried out in collaboration between both authors. Author VBS designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author EOO managed the analyses of the study and the literature searches. Both authors read and approved the final manuscript.

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ABSTRACT

The suitability of River Bonsa for drinking, without any chemical treatment was assessed using a developed and robust water quality index (WQI), with modification for the river under study. In evaluating WQI, nine parameters in water quality, which were harmful to human health were considered. They were pH, dissolved oxygen, total suspended solids, total dissolved solids, total hardness, total alkalinity, chlorides, sulphates and nitrates. On the basis of the computed WQI (55.054), River Bonsa fell within the poor for drinking water category. Hence the water needs to be treated before it can be drunk directly. Intensive education on water-related diseases is also needed to inform the inhabitants living along the river bank, who use the water from the river directly without any chemical treatment.

Keywords: River Bonsa; illegal mining; water quality index; Tarkwa; heavy metals.

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1. INTRODUCTION

The quality of water that is consumed is well-recognised as an important transmission route for infectious diarrhoea and other diseases. The importance of water quality continues to be emphasised by its role in epidemics and contribution to endemic disease from pathogens. Thus water provided for direct consumption and ingestion via food should be of a quality that does not present a significant risk to human health [1]. Water is essential as a medium for preparing food. One study noted that, the volume of cooking water available may be an important determinant for diarrhoea incidence in children over 3 years of age [2].

Water is a common chemical substance that is essential for the survival of all known forms of life. The major proportion of all water quality degradation worldwide is due to anthropogenic causes [3].

Given the importance of safe drinking water, the availability of potable water has become a daunting problem. This is especially so in developing countries, where, coupled with illegal mining and sanitation conditions that leave much to be desired, water resources have become threatened [4]. River Bonsa in Ghana runs through mining communities in a region, where legal and illegal mining are on the ascendancy. Mining has brought severe pollution to water resources and air, with devastating consequences, yet the laws that regulate Ghana's mining industry favour profit over public health and environment. Both surface and underground water have been seriously polluted through the disposal and seepage of cyanide and other harmful chemicals that pose threat to both fauna and flora. For example, on 18th June 1996, Teberebie Goldfield limited was reported to have accidentally spilt cyanide into the Angonabeng stream, the main tributary of river Bonsa, which is the main source of drinking water for the people of Tarkwa and its environs [5]. This and other unreported spillages occur in the area occasionally. Also, river Bonsa is the main source of treated water for the people of Bonsaso, and other people in the catchment area of the river, who use the water from the river directly without any treatment. Mercury, a deadly poison, has been used to extract gold for centuries because it is cheap, easy to use, and relatively efficient. Small-scale miners use mercury because it can dissolve as much as 60% of gold out of the ore.

Water quality index (WQI) gives a single value that expresses the overall water quality at a given location, based on water quality parameters that are harmful to human health. The objective of water quality index is to transform a complex water quality data into information that is understandable and usable by the public [6].

This paper assessed the water quality from River Bonsa and its impact on human health since some people in its catchment area use its water for domestic purposes without any form of chemical treatment.

2. MATERIALS AND METHODS

River Bonsa runs through the Tarkwa Nsuaem Municipal Assembly in the Western Region of Ghana and has Tarkwa as its municipal capital. The Municipality is located between latitude 4°5′ and longitude 5°5′. The Municipality has a total land area of about 905.2 square km. The Municipality is part of the Birimian and Tarkwain geological formations. Economically, the Birimian rocks are regarded as the most important formations due to its mineral potentials. These geological formations are the reasons for the existence of high mineral deposits in the Municipality. Consequently, many gold and manganese mining companies are located in the Municipality.

The Tarkwa Nsuaem Municipality lies within the south-western equatorial climatic zone. The forest is full of climbers and lianas, which are able to reach into the upper tree layer. Economic trees include mahogany, wawa, odum, sapele among others. Tarkwa Nsuaem can boast of large forest reserves like the Bonsa reserve, Ekumfi reserve, Neung south reserve and Neung north reserve. Temperature ranges between 26°C and 30°C with high relative humidity of 70 - 80% throughout the year. The Municipality experiences one of the highest rainfalls in Ghana. It has a mean annual rainfall of about 1,500 mm with a double maximum. The Municipality has a peculiar rainfall pattern, in that, during the raining season it rains usually at 2 p.m. Thus, the nickname of the Municipality is "Tarkwa at 2". River Bonsa and its numerous tributaries including Buri, Anoni, Sumin, and Ayiasu, drain the area depicting a dendritic pattern [7].

The simple grab method was used for sample collection. Samples were taken along the river during the dry and raining seasons, three times during the period of the study. A total of 30 samples were taken during the study period (10 samples during each sampling period). Samples for metal analysis were collected into acid-washed polyethene containers and acidified with 1.0 mL concentrated nitric acid per litre of sample and labelled. However, samples for physicochemical analysis were collected and stored in 250.0 mL screw-neck glass bottles without any pretreatment except for dissolved oxygen.

All samples were stored at 4°C in a refrigerator. Samples for physicochemical analysis were analysed within a week [8]. All chemicals used for the analysis were of analytical grade. The pH of the water samples was determined *in situ* with HANNA metre (model HI 9032). Other physicochemical parameters such as alkalinity, dissolved oxygen (DO) , total hardness (TH), chloride (Cl^-), sulphate (SO_4^{2-}), ammonia (NH_3-N), nitrite (NO_2-N), nitrate (NO_3-N), total solids (TS), total dissolved solids (TDS), total suspended solids(TSS) and heavy metals were measured based on water quality analysis techniques drawn from APHA [9]. The heavy metals such as total Fe, Ni, Pb, Mn, Zn, Co and Cd were also measured at the respective wavelengths by Varian Fast Sequential Atomic Absorption Spectrophotometer (AAS). Mercury was then measured by cold vapour, using 1.1% $SnCl_2$ in 3% HCl and 3% HCl as reductants at 253.7 nm wavelength.

The suitability of River Bonsa for domestic use based on water quality index of 55.054 was of poor quality (Table 3) and determined as follows:

The water quality index (WQI) was evaluated by using weighted arithmetic water quality index which was developed by Brown [10]. The weighted arithmetic water quality index is given by the equation

$$WQI_A = \sum_{i=1}^{n} wiqi / \sum_{i=1}^{n} wi \qquad \text{(i)}$$

Where *n* is the number of variables or parameters, *wi* is the relative weight of the i^{th} parameter and *qi* is the water rating factor of the i^{th} parameter. The unit weight (*wi)* of the specific water quality parameters are inversely proportional to the standard values of the corresponding parameter. It is given by

$$w_i = k/S_i \qquad \text{(ii)}$$

Where w_i is the unit weight for the i^{th} parameter, S_i is the standard value for the i^{th} parameter and k is the proportionality constant [6].

The *qi* is evaluated by the equation

$$qi = 100[(V_i - V_{id}) / (S_i - V_{id})] \qquad \text{(iii)}$$

Where V_i is the observed value of the i^{th} parameter, S_i is the standard permissible value of the i^{th} parameter and V_{id} is the ideal value of the i^{th} parameter in pure water. All the ideal values (V_{id}) are assumed to be zero (0) for drinking water except for pH and dissolved oxygen [11]. For pH, the ideal value is 7.0 (for pure water) and the permissible value is 8.5 for polluted water.

$$q_{pH} = 100[(V_{pH} - 7.0) / (8.5 - 7.0)] \qquad \text{(iv)}$$

where V_{pH} is the observed value.

For dissolved oxygen, the ideal value is 14.6 mg/L and the standard permissible value for drinking water is 5.0 mg/L. Hence its quality rating is evaluated from the equation below:

$$q_{DO} = 100[(V_{DO} - 14.6) / (5.0 - 14.6)] \qquad \text{(v)}$$

Where V_{DO} is observed value for dissolved oxygen.

The water quality index (WQI) of River Bonsa was then evaluated using the weighted arithmetic index relation

$$WQI_A = \sum_{i=1}^{n} wiqi / \sum_{i=1}^{n} wi$$

$$= \frac{37.38\ 71}{0.6\ 791} = 55.054$$

3. RESULTS AND DISCUSSION

The pH ranged from 6.02 to 7.10 with a mean of 6.45 (Table 1). The mean pH value of 6.45 was a little below the WHO standard / acceptable values of 6.5-8.5 [12]. Thus River Bonsa could be said to be weakly acid as a result of discharges of waste from the Ghana Manganese Company into the Kawire stream, one of the tributaries of River Bonsa. Acidic oxides from mine tailings and mining operations can lower the pH of water bodies.

Dissolved oxygen ranged from 6.08 mg/L to 8.0 mg/L with a mean of 7.36 mg/L (Table 1). The mean observed value of 7.36 mg/L exceeded the acceptable limit of 5.0 mg/L [12]. Oxygen enters the water from the air through rain, turbulence, wind, and through the photosynthesis of aquatic plants. Waters with higher dissolved oxygen have ecosystems that are generally more diverse and stable.

Total solids varied from 189 mg/L to 3045 mg/L with a mean of 1239.33 mg/L (Table 1). Although no acceptable limit was given, a high concentration of total solids make drinking water unpalatable and might have an adverse effect on people who are not used to drinking such water. Sources of total solids include industrial discharges, sewage, fertilizers, mine tailing runoff, and soil erosion. The large deviation in total solids might be due to seasonal changes as runoff from catchment areas of the river in raining season resulted in an increase in total solids. Total solids also affect water clarity. Higher solids decrease the passage of light through water, thereby slowing down photosynthesis by aquatic plants.

Total dissolved solids (Table 1) ranged from 113 mg/L to 184 mg/L with a mean of 137.33 mg/L. The mean total dissolved solids of 137.33 mg/L fell within the standard limit of 600.0 mg/L [12]. The sources of total dissolved solids include all of the dissolved cations and anions. The TDS concentration is more of an aesthetic rather than a health hazard. There was a slight increase in TDS during the raining season.

Total suspended solids (Table 1) ranged from 76 mg/L to 2861 mg/L with a mean of 1102 mg/L. Seasonal variation resulted in the wide variation in total suspended solids. Higher concentrations of suspended solids can serve as carriers of toxins, which readily cling to suspended particles. This is particularly a concern where pesticides are being used on irrigated crops. Where total suspended solids are high, pesticide concentrations may increase well beyond those of the original application as the irrigation water travels down irrigation ditches. Higher levels of total suspended solids can also clog irrigation devices and might become so high that irrigated plant roots will lose water rather than gain it. Total suspended solids result in turbidity. High TSS can also block light from reaching submerged vegetation, resulting in reduced photosynthesis. The decrease in water clarity caused by TSS can affect the ability of fish to see and catch food. Suspended sediment can also clog fish gills, reduce growth rates, decrease resistance to disease, and prevent their egg and larval development. High TSS can also cause problems for industrial use, because the solids may clog pipes and machinery.

The flow rate of the water body is a primary factor in TSS concentrations. Fast running water can carry more particles and larger-sized sediment. Heavy rains can pick up sand, silt, clay, and organic particles (such as leaves, soil, and tire particles) from the land and carry them to surface water. A change in flow rate can also affect TSS; if the speed or direction of the water current increases, particulate matter from bottom sediments may be re-suspended.

Total hardness ranged from 50 mg/L to 246 mg/L with a mean of 141.33 mg/L (Table 1). The mean level of 141.33 mg/L was below the guideline value of 300.0 mg/L [12]. Total hardness decrease considerably from 246 mg/L (dry season) to 50.0 mg/L (raining season). This might be due to large volume of water received by the river. However, some classification based on total hardness suggest that, River Bonsa is moderately hard ie between 75-150 mg/L [13]. Inhabitants may have to use a lot of soap when using this water to wash.

Chloride levels (Table 1) vary from 8.50 mg/L to 13.0 mg/L with a mean of 10.92 mg/L. The levels of chloride fell within the acceptable limit of 250 mg/L [12]. Environmental impact of chlorides is not usually harmful to human health. Chlorides in River Bonsa might be from rocks containing chlorides, mine tailings runoffs agricultural run-off and wastewater from industries.

Sulphate levels ranged from 4.0 mg/L to 9.0 mg/L with a mean of 6.96 mg/L (Table 1). All the levels fell within the recommended value of 250 mg/L [11]. Sulphate levels are therefore normal for domestic use.

The nitrate, nitrite and ammonia levels observed in the River Bonsa all fell within the acceptable levels of 50 mg/L, 3.0 mg/L and 1.5 mg/l respectively (Table 1). The ammonia guideline is set for aesthetic considerations rather than human health. Nitrate and nitrite are naturally occurring ions that are part of the nitrogen cycle. In general, vegetables are the main source of nitrate intake when the level in drinking water is below 10 mg/L. Nitrites also react directly with haemoglobin in human blood and other warm-blooded animals to produce methemoglobin.

Methemoglobin destroys the ability of red blood cell to transport oxygen. This condition is especially serious in babies under three months of age, a condition known as methemoglobinemia or "blue baby syndrome" [14].

Total alkalinity (Table 1) ranged from 40.0 mg/L to 50.0 mg/L with a mean of 44.0 mg/L. Total alkalinity fell within acceptable level of 500.0 mg/L [12]. Alkalinity refers to the capability of water to neutralize an acid. This is really an expression of buffering capacity. Alkalinity is important for fish and aquatic life because it protects or buffers them against rapid pH changes. The main sources for natural alkalinity are rocks which contain carbonate, bicarbonate, and hydroxide compounds.

Iron in the water (Table 2) ranged from 1.86 mg/L to 3.15 mg/L with a mean of 2.35 mg/L. The mean of 2.35 mg/L was more than seven times higher than the standard value of 0.3 mg/L for Fe [12]. Iron in domestic water supply system, stains laundry and porcelain. It appears to be more of a nuisance than a potential health hazard. Taste thresholds of iron in water is about 0.1 mg/L for ferrous iron and 0.2 mg/L ferric iron, giving a bitter or an astringent taste. Water used in industrial processes usually contains less than 0.2 mg/L iron. There was a general increase in metal levels during the raining season. This might be due to leachates from the runoff [14].

Iron is an essential trace element in living organisms. Most iron is absorbed in the duodenum. Absorption depends on the individual's iron status and is regulated so that excessive amounts of iron are not stored in the body. Estimates of the minimum daily requirement for iron depend on age, sex, physiological status, and iron bioavailability and range from about 10 to 50 mg/day [15].

Nickel concentration varied from 0.01 mg/L to 0.02 mg/L with a mean of 0.013 mg/L (Table 2). The level of Ni in the water fell within the standard guideline value [12]. The accepted concentration of nickel in raw water is found to be 0.05 mg/L and in treated water, it is 0.02 mg/L. However, exposure to Ni may cause lung cancer and disorders of the respiratory system. Nickel is a well-known human carcinogen and it affects the activity of α-tocopherol, the most common antioxidant in the human body [16].

Lead was below the detection limit in some samples. However, the observed maximum lead level was 0.7 with a mean of 0.023 mg/L (Table 2). The mean level of Pb was above the standard value of 0.01 mg/L [12]. Lead is persistent, and it can bioaccumulate in the body over time. Young children, infants, and foetuses are particularly vulnerable to lead because the physical and behavioural effects of lead occur at lower exposure levels in children than in adults. A dose of lead that would have little effect on an adult can have a significant effect on a child. In children, low levels of exposure have been linked to damage to the central and peripheral nervous system, learning disabilities, shorter stature, impaired hearing, and impaired formation and function of blood cells.

Manganese concentrations (Table 2) varied from 0.13 mg/L to 0.27 mg/ L with a mean of 0.21 mg/L. All these levels were within the acceptable limit of 0.4 mg/L [12]. Manganese concentration in raw water is 0.03 mg/L. After treatment, the concentration of this element increases slightly to 0.05 mg/L which still falls within the limit of drinking water. The function of this element in human is not fully understood, however, it is very important for plants [15].

Mercury (Table 2) ranged from 1.82 mg/L to 1.97 mg/L with a mean of 1.93 mg/L. The mean level of 1.93 mg/L was more than 321 times above the standard guideline value of 0.006 mg/L of Hg [12]. The high Hg levels might be due to increase in illegal mining in which Hg is the common chemical that is used by the miners. Mercury may be converted to methylmercury and greatly increases its toxicity, which has the potential for accumulation in aquatic biota.

Cadmium concentration (Table 2) varied from 0.036 mg/L to 0.052 mg/L with a mean of 0.041 mg/L. The mean concentration of 0.041 mg/L was more than 13 times higher than the guideline value of 0.003 mg/L [12]. The primary source of Cd into River Bonsa might be the Cd leachates from the mine tailings. Rivers containing excess cadmium can contaminate surrounding land, either through irrigation for agricultural purposes, dumping of dredged sediments or flooding. Cadmium has no known beneficial function in the human body. Cadmium accumulates in animal tissue, and its toxicity can increase as accumulation increases. Cadmium causes cancer, birth defects, and genetic mutations. The dreadful disease, known as *Itai-Itai* was the result of water contamination by cadmium from mining waste in Japan [14].

Table 1. Mean levels of physicochemical parameters in River Bonsa

Parameters n==30	pH	DO mg/L	TS mg/L	TSS mg/L	TDS mg/L	TH mg/L	Cl^- mg/L	SO_4^{2-} mg/L	$N0_2^-N$ mg/L	NO_3^-N mg/L	HN_3-N mg/L	Total alkalinity mg/L
Mean	6.45	7.36	1239.33	1102.0	137.33	141.33	10.92	6.96	0.02	0.27	0.53	44.0
SD	0.57	1.11	1570.0	1530	40.43	98.67	2.26	2.23	0.01	0.11	0.46	5.29
Min	6.02	6.08	189.0	76	113.0	50.0	8.50	4.0	0.01	0.16	0	40.0
Max	7.10	8.0	3045.0	2861	184.0	246.0	13.0	9.0	0.03	0.37	0.81	50.0
WHO (2011) limit	6.5-8.5	5.0	-	-	600	300.0	**250.0**	**400.0**	**3.0**	**50.0**	**1.5**	**500.0**

Table 2. Mean heavy metal levels of River Bonsa

Parameters n-30	Fe mg/L	Ni mg/L	Pb mg/L	Mn mg/L	Hg mg/L	Cd mg/L	Co mg/L	Zn mg/L
Mean	2.35	0.013	0.023	0.21	1.93	0.041	0.18	0.032
SD	0.70	0.005	0.04	0.07	0.096	0.008	0.17	0.002
Min	1.86	0.01	0	0.13	1.82	0.036	0.073	0.031
Max	3.15	0.02	0.7	0.27	1.97	0.052	0.38	0.035
WHO (2011)	0.3	0.07	0.01	0.4	0.006	0.003	-	3.0

Table 3. Water quality index (WQI) of River Bonsa

Parameter	Observed values	Standard value (s_i)	Unit weight (w_i)	Quality rating q_i	W_i q_i
pH	6.45	6.5-8.5	0.218176	36.67	8.0
Dissolved oxygen (mg/L)	7.36	5.0	0.37089	75.42	27.97
Total alkalinity (mg/L)	44.0	500.0	0.0155	8.8	0.136
Total hardness (mg/L)	141.33	300.0	0.0062	47.11	0.2920
Total suspended solids (mg/L)	1102	500.0	0.0037	220.4	0.8155
Chlorides (mg/L)	10.92	250.0	0.0074	4.37	0.03234
Nitrate (mg/L)	0.27	50.0	0.0412	0.54	0.022248
Sulphate (mg/L)	6.96	250.0	0.01236	2.78	0.03436
Total dissolved solid (mg/L)	137.33	600.0	0.0037	22.88	0.084656
			$\sum$ Wi=0.6791	$\sum \mathrm{qi} = 418.97$	$\sum \mathrm{wiqi} = 37.3871$

Cobalt levels ranged from 0.073 mg/L to 0.38 mg/L with a mean of 0.18 mg/L (Table 2). Cobalt is an integral part of vitamin B_{12} and essential for the production of red blood cells. Salts of cobalt such as acetate, chloride, and sulphates are highly toxic to human beings [14].

The levels of Zn ranged from 0.031 mg/L to 0.035 mg/L with a mean of 0.32 mg/L (Table 2). All these levels were within the standard value of 3.0 mg/L [12]. Zinc is an essential element and is generally considered to be non-toxic. Intake of Zn from food is more than sufficient to satisfy the recommended daily requirements. However, drinking water is not an important nutritional source of this element.

The calculated WQI value (55.054) fell within 51-75 category of water quality based on weighted arithmetic WQI method shown in Table 3. Based on the calculated WQI, River Bonsa is of poor quality, hence cannot be used directly for drinking without treatment to avoid water-related diseases.

4. CONCLUSIONS

River Bonsa is of poor quality based on the calculated WQI of 55.054 and hence cannot be drunk directly without any chemical treatment. Drinking untreated water from River Bonsa is likely to result in water-related diseases among the inhabitants in the catchment area of the river. Education on water-related diseases should be strengthened in the catchment area of the river in order for the inhabitants to make informed choices. Mining companies in the area should be made to extend their co-operate responsibility to the people by providing them with alternative sources of potable water. Government should also play its role by providing potable water to its people.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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